GUIDELINES FOR REFRACTORY ALLOY TUBING SPECIFICATIONS

MAB

MATERIALS ADVISORY BOARD

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES/NATIONAL ACADEMY OF ENGINEERING

51

MATERIALS ADVISORY BOARD
DIVISION OF ENGINEERING - NATIONAL RESEARCH COUNCIL

7-67

GUIDELINES FOR REFRACTORY ALLOY TUBING SPECIFICATIONS

Prepared by

THE COMMITTEE ON TUBING

MATERIALS ADVISORY BOARD

Division of Engineering - National Research Council

Publication MAB-232

National Research Council

National Academy of Sciences - National Academy of Engineering

Washington, D. C.

October 1967

This report is one of a series in a study undertaken by the Materials Advisory Board for the National Academy of Sciences in partial execution of work under Contract No. DA-49-083 OSA-3131 between the Department of Defense and the National Academy of Sciences.

The National Research Council, under the cognizance of both Academies, performs study, evaluation or advisory functions through groups composed of individuals selected from academic, governmental, and individual sources for their competence or interest in the subject under consideration. Members of these groups serve as individuals contributing their personal knowledge and judgments and not as representatives of any organization in which they are employed or with which they may be associated.

For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia, 22151. Price $3.00 (Paper) $0.65 (Microfiche).

MATERIALS ADVISORY BOARD

COMMITTEE ON TUBING

Chairman: Mr. David C. Goldberg, Manager
Materials Department
Astronuclear Laboratory
Westinghouse Electric Corporation
Box 10864
Pittsburgh, Pennsylvania 15236

Members

Mr. G. M. Ault, Associate Chief
Materials & Structure Division
Lewis Research Center, NASA
21000 Brookpark Road
Cleveland, Ohio 44135

Dr. William O. Harms
Nuclear Division
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, Tennessee 37831

Mr. Alexander Krivetsky
Chief, Structural Methods
Structural Dynamics Section
Structural Systems Department
Bell Aerosystems Company
Buffalo, New York 14240

Dr. David W. Levinson
Professor of Metallurgy
Department of Materials Engineering
College of Engineering
The University of Illinois
P. O. Box 4348
Chicago, Illinois 60680

Mr. Ross Mayfield
Argonne National Laboratory
9700 South Cass Street
Argonne, Illinois 60440

Dr. J. W. Semmel, Jr.
Manager, Materials and
Processes
Space Power & Propulsion Section
General Electric Company
Cincinnati, Ohio 45215

Mr. William Thurber
Fuel Cell Department
Electronics Division
Union Carbide Corporation
P. O. Box 6116
Cleveland, Ohio

Mr. E. D. Weisert, Manager
Metals Research Division
Rocketdyne Division of NAA
6633 Canoga Avenue
Canoga Park, California 91304

Liaison

DOD	Mr. John Barrett, ODDR&E, Office of Assistant Director for Chemical Technology, Room 3D117, The Pentagon, Washington, D. C.
Air Force	Mr. George Glenn, Code MATB, Wright-Patterson AFB, Ohio 45433
Army	Mr. S. V. Arnold, Army Materials and Mechanics Research Center Watertown, Massachusetts 02172
NASA	Mr. John Milko, Lewis Research Center, NASA, 21000 Brookpark Road, Cleveland, Ohio 44135
AEC	Mr. Andrew Van Echo, Reactor Development Division, Atomic Energy Commission, Washington, D. C. 20545

MAB Staff: Dr. J. R. Lane
Staff Metallurgist
Materials Advisory Board
National Research Council
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

CONTENT

CONTENT (cont'd.)

APPENDICES

INTRODUCTION

The intent of the work described herein is to provide guidelines in the preparation of specifications for the procurement of tubing fabricated from alloys based on molybdenum, columbium, tantalum, vanadium, and tungsten for advanced engineering systems.

The material presented is intended to be sufficiently general so that it can be readily adapted to specific tubing requirements. An effort has been made to include only product specifications. References to process requirements should apply only in research and development and similar situations where standard industrial plant procedures are considered to be not sufficiently developed to ensure the desired product quality.

It is improbable that the limitations, property levels, etc. described are applicable in their entirety to any given application. For example, tungsten and molybdenum tubing would not be installed using flared joints--hence the flareability requirement (sections 3.7.3 and 4.6.3) is not appropriate. Similarly, it is important to heat-treat columbium and tantalum in a high vacuum to obviate contamination. For tungsten and molybdenum, a hydrogen atmosphere might be acceptable or preferable. In terms of applications, the requirement for straightness (section 3.8.3) may be unimportant for small assemblies. Special sizes (ery thick walls or diameter ov r 5 inches) will call for many variations (grain size, permissible contamination, etc.) from the values stipulated herein for usual sizes. Composite tubing will call for additional controls beyond those indicated in this report. These guidelines, therefore, comprise a checklist, first of all, of items to be considered. Second, suggested values, which are considered to be attainable and which provide for a usable product, are given. Certain applications may require other levels, and in some cases (sections 3.7.1 and 3.7.2--Tensile and Creep-Rupture Properties) the level is so related to the application that no numbers are suggested--the user must define his own requirement. The user will recognize that it may be difficult to persuade a producer to accept an order to an unduly stringent specification. Furthermore, an order calling for small quantities of a developmental alloy will be produced in a development or semiproduction

facility, under conditions wherein compromises involving quality, dimensional tolerances, properties, price, and delivery schedule may be necessary.

On the subject of nondestructive testing, no attempt is made to prescribe a procedure as it was considered beyond the scope of the present report. It should be noted that many tube producers are not equipped to use procedures that some tube users believe are required. Three preliminary methods for ultrasonic inspection, and a section on tubing dimensional tolerances are included in the Appendices.

The content of this document is based on information gleaned from the experience of both producers and users of refractory alloy tubing. Reference data and comments were obtained from organizations listed below:

Bell Aerosystems Company
P. O. Box 1
Buffalo, New York 14240

General Electric Company
Nuclear Materials and Propulsion Operation
Cincinnati, Ohio 45215

General Electric Company
Space Power and Propulsion Section
Missile and Space Division
Cincinnati, Ohio 45215

Magnaflux Corporation
700 West Lawrence Avenue
Chicago, Illinois 61656

National Aeronautics & Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, Tennessee 37831

Superior Tube Company
Norristown, Pennsylvania 19404

Westinghouse Electric Corporation
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

Literature references used in preparation of this document are given below.

<u>Aerospace Materials Specifications</u> - Society of Automotive Engineers.

<u>Material Specifications</u> - Section II, ASME Boiler and Pressure Vessel Code.

R. T. Fling, "Tubing for Mating Parts," <u>Machine Design</u>, February 3, 1966.

Materiel and Processes Manual No. 233. <u>Materials in Design Engineering</u>, September 1965.

W. O. Nussear, "How to Choose and Use Tubing," <u>American Machinist</u>, June 1, 1959.

This report has been reviewed and approved by the Tubing Committee of the Materials Advisory Board. Special recognition, however, is due one member of the Committee, Mr. Alexander Krivetsky, who drew up successive drafts of this document and incorporated numerous changes.

GUIDELINES FOR REFRACTORY ALLOY TUBING SPECIFICATIONS

1. SCOPE

1.1 This specification applies to tubing of refractory alloys based on molybdenum, niobium, tantalum, vanadium, and tungsten, intended for advanced, high-temperature engineering applications.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of invitation for bids, shall, to the extent designated herein, form a part of the specifications.

Document Number	Title
ASTM Designation E8	Method of Tension Testing of Metallic Materials
ASTM Designation E29	Recommended Practices for Designating Significant Places in Specified Limiting Values
ASTM Designation E112	Estimating Average Grain Size of Metals
ASTM Designation 213-63	Ultrasonic Inspection of Metal Pipe and Tubing for Longitudinal Discontinuities
ASTM Designation E92	Test for Diamond Pyramid Hardness of Metallic Materials
AMS 2635	Radiographic Inspection
AMS 2645	Fluorescent Penetrant Inspection
AMS 2646	Contrast Dye Penetrant Inspection

Federal Test Method Standard No. 151	Metals, Test Methods
MIL-STD-10	Surface Roughness Waviness and Lay
MIL-STD-163	Steel Mill Products Preparation for Shipment and Storage
MIL-STD-129	Marking for Shipment and Storage
MIL-STD-183	Continuous Identification Marking of Iron and Steel Products
MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MS 33584	Tubing End, Standard Dimensions for Flared

2.2 Copies of Federal and MIL Standards required by contractors in connection with specific procurement functions should be obtained as indicated in the Department of Defense Index of Specifications and Standards. Copies of ASTM Standards should be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103. Copies of AMS Specifications can be obtained from the Society of Automotive Engineers Incorporated, 485 Lexington Avenue, New York, New York 10017.

3. REQUIREMENTS

3.1 Acknowledgments. The vendor shall mention this specification in all quotations and all purchase order acknowledgments.

3.2 Manufacture. Material covered by this specification shall be made by any methods that produce the end requirement.

3.3 Processing. The starting stock size, processing temperatures, percentages of reduction, in-process annealing temperatures and times shall be selected by the vendor to achieve the metallurgical and mechanical properties required by this specification.

3.4 Condition

3.4.1 General. The finished product will be supplied in the $\boxed{\quad\quad}$ condition throughout the cross-sectional area to the grain size range specified in paragraph 3.6.

3.4.2 Heat Treatment. All mill products to be annealed shall be thoroughly degreased, chemically cleaned and, where necessary, protected from furnace parts by a layer of foil. The conditions of final annealing, if required, shall be reported in the certificate of compliance.

3.4.3 Contamination. All items are to be free of contamination or internal oxidation. After final heat treatment, the material samples shall be examined metallographically for evidence of possible contamination caused by unsatisfactory heat treating atmospheres or processing conditions. A microhardness traverse shall show a hardness change not greater than $\boxed{\quad}$ VHN from the center to the surface of a cross-sectional sample of the final product. At the discretion of the purchaser, samples taken to include at least one surface of the final product, and not exceeding 0.050-inch thick, may be chemically analyzed by the purchaser for oxygen, nitrogen, hydrogen and carbon. The analyses shall not exceed the limits set forth in paragraph 3.5.3. Any indication of contamination shall be cause for rejection of all material represented by that sample. The material shall be acceptable if the contaminated layer is completely eliminated before shipment by a rework operation within the specified dimensions and tolerances.

3.5 Chemical Composition

3.5.1 Ingot-Billet Composition. The chemical composition of ingots and billets for conversion to finished products shall conform to Table A1 in Appendix A (which is a suggested format for such a table). A minimum of three analyses shall be obtained, one each at the top, center, and bottom in either ingot or billet (immediately after primary breakdown) or a combination of ingot and billet.

3.5.2 Final Product Composition. At the discretion of the purchaser, final products may be analyzed to determine the metallic elements stated in Table A1, Appendix A. Failure of the analyses to conform with the requirements of Table A1 shall be cause for rejection of all material represented by the analytical sample. If, at the discretion of the purchaser, the final products are not analyzed for metallic elements, the manufacturer's ingot analysis in accordance with paragraph 3.5.1 shall be considered the chemical analysis for the metallic elements of products supplied under this specification. In all cases, the carbon, oxygen, nitrogen, and hydrogen content of finished products shall be determined as a check analysis of the nonmetallic elements.

3.5.3 Check Analysis. The finished product analysis shall not exceed the following limits or variations. The values outlined in Table 1 are illustrative sample values that match the composition given in Table A1 in Appendix A and are included to indicate acceptable limits of variation to the purchaser.

TABLE 1 - CHECK ANALYSIS CHEMISTRY LIMITS
(The limits shown are illustrative, and are not valid for all alloys, nor for all applications)

For Wall Thicknesses 0.020 Inch or Greater		
Element	Check Analysis Limits, Max, ppm	Permissible Variations in Check Analysis, ppm
Carbon	50	± 10
Oxygen	150	± 20
Nitrogen	75	± 10
Hydrogen	10	± 2
For Wall Thicknesses Less than 0.020 Inch		
Element	Check Analysis Limits, Max, ppm	Permissible Variations in Check Analysis, ppm
Carbon	75	± 10
Oxygen	200	± 20
Nitrogen	100	± 10
Hydrogen	10	± 2

3.6 Grain Size. The grain size of the final products shall typically conform to the following limits:

TABLE 2 - GRAIN SIZE

Product Wall Thickness, Inches	ASTM Grain Size Range		Minimum Percent Recrystallization
Less than 0.010	7-9	Increasing	100
0.010 to 0.065	6-8	Grain Size	100
0.065 to 0.125	5-7		100
0.125 to 0.250	4-6		95
0.250 to 0.500	3-6		90

NOTE: The above listed values of grain size are merely illustrative values and are not valid for all alloys and materials.

3.7 Mechanical Properties. The final product shall satisfy the following mechanical property requirements.

3.7.1 Room Temperature Tensile Properties. Representative material samples of tubing shall comply with the following property limits at room temperature (65°-85°F), or above the ductile-brittle transition temperature.

TABLE 3 - MECHANICAL PROPERTIES

Ultimate Tensile Strength, psi		Yield Strength (0.2 Percent Offset), psi		Elongation, Percent
Minimum	Maximum	Minimum	Maximum	Minimum
-	-	-	-	-

3.7.2 Creep-Rupture Properties.

3.7.2.1 Stress-to-Rupture Properties. The material samples shall be capable of achieving the following stress-rupture properties under suitable environmental conditions.

TABLE 4 - STRESS-RUPTURE PROPERTIES

Temperature Deg. F (C)	Stress, psi (Kg/mm^2)	Minimum Rupture Life Hrs.	Minimum Fracture Elongation Percent
-	-	-	-

3.7.2.2 Creep Properties. The material samples shall be capable of achieving the following creep properties under suitable environmental conditions.

TABLE 5 - CREEP PROPERTIES

Temperature Deg. F (C)	Stress, psi (Kg/mm^2)	Maximum Strain After __ Hours at Indicated Stress (Based on __ Gage Length)
-	-	-

3.7.2.3 Chemical Analysis of Creep-Rupture Specimens. Chemical analyses of creep-rupture specimens after test shall demonstrate that the degree of environmental contamination did not exceed the following limits: total change in oxygen plus nitrogen content--less than 50 ppm; increase in hydrogen content--less than 5 ppm; increase in carbon content--less than 10 ppm. The following limits shall apply to check analyses of the analytical results:

Carbon	±	10 ppm
Oxygen	±	25 ppm
Nitrogen	±	25 ppm
Hydrogen	±	2 ppm

(The figures listed in the rectangle are sample values commensurate with Table A1 in Appendix A.)

The following three reports are recommended to those concerned with the problem of chemical analysis of refractory metals:

MAB-178-M Report of the Subpanel on Analytical Techniques, Refractory Metals Sheet Rolling Program November 15, 1961

MAB-217-M Cooperative Analysis Program on Refractory Metals Alloys, February 1966

DMIC 220 Comparison of Chemical Analysis of Refractory Alloys, D. L. Chase

3.7.3 Flareability. Tubing, 0.125 inch outside diameter and over, shall flare without rupture, when testing as specified in 4.6.3. The flared zones shall be sound, uniform, and smooth.

3.7.4 Flattening. Tubing shall not develop cracks, tears, or flaws when subjected to the flattening test specified in 4.6.4.

3.7.5 Hydrostatic Pressure Resistance. When subjected, by the method specified in 4.6.5, to an internal pressure P, tubing shall show no bulging, leakage, or other defects except that a diametric permanent set of 0.002 inch per inch of diameter is acceptable. Hydrostatic test pressure shall be calculated using the following formula:

$$P = \frac{2\,St}{D}$$

where:

P = hydrostatic test pressure, psi

S = specified fiber stress, psi, or 0.8 of the minimum yield strength furnished (See Table 3)

t = minimum wall thickness in inches; equal to the specified average wall minus the permissible "minus" wall tolerance (Appendix B), or the specified minimum wall thickness

D = outside diameter of the tube in inches

3.7.6 Hardness. Tubing shall have a maximum hardness of $\boxed{}$

3.8 Tolerances. (A short presentation on tubing tolerances is given in Appendix B which also includes definitions and mating fits. The values shown are general and can be adjusted to comply with vendor or user requirements.)

3.8.1 Diameter and Wall Thickness. The permissible variations in diameter and wall thickness of tubing are illustrated in Table 6.

3.8.2 Length. When tube is ordered cut-to-length, the usable length shall not be less than that specified, but a variation of plus 1/8 inch will be permitted in lengths up to 6 feet. In lengths over 6 feet, a variation of plus 1/4 inch will be permitted, unless otherwise specified.

TABLE 6 - VARIATIONS IN TUBE DIMENSIONS

Nominal OD, Inches	OD, Inch	ID, Inch	Wall Thickness, Percent
0.187 to 0.25	± 0.002	± 0.002	± 10
0.25 to 1.000	± 0.005	± 0.005	± 10
1.000 to 2.000	± 0.0075	± 0.0075	± 10
2.000 to 3.000	± 0.010	± 0.010	± 10
3.000 to 4.000	± 0.0125	± 0.01	± 10

NOTES TO TABLE 6:

(1) Tolerances are applicable to only the two dimensions specified on the purchase order, e.g., outside diameter and wall, inside diameter and wall, outside diameter and inside diameter.

(2) For tolerances applicable for very small tubes (less than 0.187-inch diameter) or very thin-wall tubes (less than 0.010-inch thick), the producer shall be consulted.

(3) For tubes having an inside diameter less than 60% of the outside diameter or a wall thickness of 3/4 inch or more, which cannot be successfully drawn over a mandrel, the inside diameter may vary by an amount equal to plus or minus 10% of the wall thickness. The wall thickness of these tubes may vary plus or minus 12.5% from that specified.

(4) Ovality measured at any cross section: for tubes with nominal wall thickness less than 3% of the nominal outside diameter, the ovality tolerances are double the tolerances in column 2 or 3. For ovality tolerances for tubes with wall thickness less than 2% nominal outside diameter, the producer shall be consulted.

3.8.3 Straightness. The tube shall be free of bends or kinks. For lengths up to 10 feet, the maximum bow shall not exceed one part in 1200; for lengths greater than 10 feet, the maximum bow shall not exceed one part in 600.

3.8.4 Surface Finish. Surface roughness shall not exceed RMS ______ as defined by MIL-STD-10.

3.9 Maximum Allowable Discontinuities.

3.9.1 General. All ID and OD surfaces shall be smooth in appearance and be free from surface films, scale, carbonaceous residue, heat discoloration, flakes, slivers, burrs, and loose or adherent particles of foreign matter. All chemical bath residues shall have been removed by rinsing in hot flowing water followed by thorough drying.

3.9.2 Porosity and Inclusions. Discontinuities with radial dimensions greater than ______ of the wall thickness or ______ inch, whichever is greater, shall be unacceptable with a minimum rejectable indication of ______ inch. The method of inspection (x-ray, ultrasonic, etc.) shall be indicated.

3.9.3 Optional Surface Rework. Defects less than ______ % of the nominal wall thickness or ______ inch, whichever is smaller, detected by penetrant or ultrasonic inspection may be removed by grinding provided the wall thickness is not decreased below that permitted in Table 6. Surface improvement of tubing shall be permitted only to the extent that a localized area no more than 1 foot in length in each 6-foot length of tubing may be blocked off and polished or buffed. These operations shall not thin out the tubing below the minimum diameter and wall thickness tolerances.

NOTE: Entire lengths of tubing shall not be subjected to buffing operations.

4. QUALITY ASSURANCE PROVISIONS

4.1 Vendor Responsibility. The manufacturer shall make all tests and inspections of the material covered by this specification before shipment

unless otherwise specified. All test and inspection results shall be furnished to the purchaser. Unless otherwise specified in the purchase order, the vendor shall be responsible for the performance of all inspection requirements, as specified herein, utilizing his own facilities or any commercial laboratory mutually acceptable to the purchaser and vendor. Inspection records of the examination and tests shall be kept complete and available to the purchaser. The purchaser reserves the right to perform any of the inspection specified herein, when these inspections are deemed necessary to assure that the supplies and services conform to the prescribed requirements. If the material, when tested, does not conform to the prescribed requirements, it shall be subject to rejection.

4.2 <u>Customer Review</u>. The purchaser or his representative may witness the testing and inspection of the material. The manufacturer shall give the purchaser ample notice of the time and place of designated tests. If the purchaser's representative is not present at this time and a new date is not set, the requirement of purchaser's inspection at the place of testing is waived. When the purchaser's representative is present at the appointed time and place, the manufacturer shall afford him, without charge, all reasonable facilities to assure that the material is being furnished in accordance with this specification. This inspection shall not interfere unnecessarily with production operation.

4.3 <u>Material Sample Selection</u>. Care shall be exercised to insure that the sample selected for testing is representative of the material and uncontaminated by the sampling procedure. If there is any question about the sampling technique or the analysis, the methods for sampling and analysis shall be those agreed to by the buyer and seller. The specimen configuration selected for the performance of the testing required in paragraphs 4.6.2 and 4.6.7 shall be mutually agreed upon by the vendor and purchaser prior to placement of a purchase order. The location of all test samples shall be reported in the certificate of compliance.

4.3.1 <u>Surface Contamination</u>. Any sample or specimen exhibiting obvious surface contamination or other defects which are obviously the result of

improper preparation will be disqualified as a truly representative sample and replaced.

4.4 Material Certification. Each lot of material, submitted for acceptance, shall be accompanied by a test report, in triplicate, indicating compliance with all of the requirements of this specification. This test report shall include actual numbers for chemical composition and tensile strength, and shall state that the surface finish, tolerances and markings, nondestructive tests, flaring test, flattening test, and hydrostatic pressure resistance test are all acceptable. The report shall also include the purchase order number, lot number, heat number size and quantity from each lot, and this specification number $\boxed{}$.

4.4.1 Material Replacement. When defects, as defined herein, are found or exposed subsequent to delivery, the vendor shall be responsible for replacing the defective material without expense to the purchaser.

4.5 Subcontractor Certification. When material for subcontract parts is purchased directly by the part subcontractor, the subcontractor shall be responsible for determining that each lot of material conforms to the requirements of this specification. With each part shipment to the purchaser, the subcontractor shall submit (in triplicate) a copy of the report specified in paragraph 4.4.

4.6 Test Methods.

4.6.1 Chemical Analysis. Chemical analyses shall be conducted by mutually acceptable procedures, such as the vacuum fusion methods for gases, the combustion method for carbon, and the spectrochemical methods for metallic elements.

4.6.2 Tensile Test. Samples shall be tested as full tube specimens with a test section of not less than 6 inches between plugs, as shown in Fig. 1 of Federal Test Method Standard 151, Method 211. In larger diameters, Type T1 or T2 specimens, as specified in Federal Test Method Standard 151, Method 211, may be used. The tests shall comply with the applicable requirements of Federal Test Method Standard 151, Method 211.

4.6.3 Flaring Test. Samples selected in accordance with paragraph 4.6.1 shall be flared by spinning or by forcing axially over a tapered pin. (For the flare test without spinning, the specimen shall be 1 inch or 1.5 times the diameter in length.) The end of each specimen to be flared without spinning shall be cut square, with the cut end smooth and free from burrs but with the corners not rounded. The specimen shall, at room temperature, be forced axially by steady pressure over a hardened and polished tapered steel pin to produce the flared tubing configuration specified in MS 33584. Both the tube and the pin shall be clean and dry during the flaring operation. Surfaces of flares shall be examined at a magnification of 3 to 5X for freedom from cracks and other defects.

4.6.4 Flattening Test. Specimens, 1 inch or more in length (3 inch minimum for sector specimens), shall be cut from sample tubes. Specimens shall be flattened cold between parallel plates until the distance between the plates is not greater than four times the nominal wall thickness. When the tubing inner diameter is less than three times the wall thickness, specimens shall be split longitudinally, opened until almost flat, then bent transversely (mandrel transverse to tube axis) around a mandrel, whose diameter is equal to twice the wall thickness, with the inner surface of the tube becoming the outer surface of the bend. Bend areas shall be examined at a magnification of 3 to 5X for the presence of cracks or tears.

4.6.5 Hydrostatic Pressure Resistance. Two samples, each one consisting of a full length of tubing, shall be selected to represent each lot, one from the beginning and the other late in the production sequence. Sample tubes shall be subjected to internal hydrostatic pressure calculated in accordance with 3.7.5. Normally, tubing shall be pressurized to only 80% of the yield strength (S as defined in section 3.7.5.)

4.6.6 Helium Leak Test. For this leak test (when required), each tube shall be subjected to an internal pressurization of 500 psi gage effected by 100% helium for 10 minutes. No leaks shall be permitted as indicated by a method other than mass spectrometer leak detection. The leakage rate as shown by the mass spectrometer shall not exceed 5×10^{-8} standard cubic centimeters per second. The manufacturer shall submit details of the test

method including a description of the equipment used and of the testing technique, and obtain purchaser's approval before starting production.

4.6.7 Stress-Rupture and Creep Tests. Creep-rupture properties of specimens shall be determined by mutually acceptable testing techniques. Suggested testing technique for determining stress-rupture properties are listed below.

4.6.7.1 Specimens shall be tested at pressures of 1×10^{-6} Torr or less. The vacuum system shall incorporate a liquid nitrogen cold trap or a getter-ion pumping.

4.6.7.2 Specimens shall be held for a half hour at the test temperature before application of load.

4.6.7.3 Test temperature shall be maintained at plus or minus 10°F of the indicated temperature during the test.

4.6.8 Grain Size. Grain size determinations shall be made according to ASTM Specification E112, "Estimating the Average Grain Size of Metals."

4.6.9 Hardness Test. The preparation of the specimen and performance of the test shall be in accordance with ASTM Designation E92.

4.6.10 Number of Tests Required. Representative test specimens from the finished product representing each ingot and each lot of material shall be taken to determine conformity to this specification. The minimum frequency of these tests shall be as illustrated in Table 7.

TABLE 7 - MATERIAL TEST FREQUENCY

Test	Number Per Lot
Finished Product Chemistry	1
Tensile Test	2
Stress-Rupture Test	2
Creep Tests	2
Flare Test	2
Flattening Test	2
Grain Size	2
Hardness	1
Hydrostatic Proof Test	2
Helium Leak Test	100%

4.6.11 Rework and Retest. If inspection and test results of a lot do not conform to the requirements of this specification, the lot may be reworked at the option of the manufacturer. The lot shall be acceptable if all test results, after reworking, conform to this specification.

4.7 Inspection.

4.7.1 Methods of Inspection. The tubing manufacturer shall submit details of the inspection procedure including a description of the equipment used, the testing technique, calibration standards and acceptance criteria, and obtain purchaser's approval before starting production.

4.7.1.1 Radiographic. Although usually not applicable, when specified, the product shall be radiographed and found free of porosity and inclusions as specified in paragraph 3.9.2, using techniques described in AMS 2635, "Radiographic Inspection." The radiographs and product shall be identified so that the exact position of each radiograph can be correlated with the specific area on a particular product.

4.7.1.2 Ultrasonic Inspection. Unless otherwise agreed to by the purchaser and the vendor, the material shall be inspected ultrasonically. Several methods are described in Appendix C.

4.7.1.3 Penetrant Inspection. When specified, the exterior surface of the product shall be penetrant inspected and found free of flaws as specified in paragraph 3.9.2, using AMS 2645, "Fluorescent Penetrant Inspection," or AMS 2646, "Contrast Dye Penetrant Inspection." All parts thus inspected shall be marked with ink stamps as described in the specification; impression stampings or etching shall be unacceptable.

4.7.1.4 Reports. The manufacturer shall supply as least three copies of a report showing nonproprietary manufacturing methods, processing conditions, test procedures and results and inspection results for each lot of material in the shipment. The report shall also include the number of the specifications and the purchase order or contract number.

4.7.2 Rejection. Material not conforming to this specification or to any authorized modification shall be subject to rejection. Unless otherwise specified, rejected material may be returned to the manufacturer at the manufacturer's expense if the purchaser does not receive other instructions for disposition within three weeks after notice of rejection.

4.7.3 Referee. If the manufacturer and the purchaser disagree concerning the conformance of the material to the requirements of this specification or any special test specified by the purchaser, a test performed by a mutually acceptable referee shall be used to determine conformance.

5. PREPARATION FOR DELIVERY

5.1 Identification. Each bundle, box or carton shall be legibly and conspicuously marked or tagged with the number of this specification, purchase order or contract number, type, ingot number, lot number, nominal size, and the gross, net and tare weights. When each bundle, box, or carton consists of components from more than one ingot number or lot number, each component shall be identified individually. Refer to MIL-STD 183.

5.2 Packing. The ends of each pipe or tube shall be sealed with suitable plastic caps and each individual item shall be wrapped in heavy gage polyethylene or similar material and packed in a manner assuring safe delivery when properly transported by a common carrier. Refer to MIL-STD 129.

6. DEFINITIONS

6.1 Lot. A lot shall include all material of the same size, shape, condition and finished from one heat of material and which has received the same processing, has been annealed in the same annealing charge and has been processed simultaneously in all operations in which temperatures may reach 500^{o}F or above. When process temperatures and environments are closely controlled or when closely adjacent sizes receive similar processing, lots may be combined for chemical, tensile and stress-rupture tests only, provided prior written approval has been obtained from the purchaser.

6.2 Check Analysis. An analysis may be requested by the purchaser of the metal after it has been processed into finished mill forms, to verify the composition within a heat or lot. Check analysis tolerances do not broaden the specified heat analysis requirements but rather cover variations between laboratories in the measurement of the chemical content.

6.3 Significance of Numerical Limits. For determining compliance with the specified limits for requirements of the properties listed below, an observed value or a calculated value shall be rounded off using the rounding-off method in ASTM Designation E29, "Recommended Practices for Designating Significant Places in Specified Limiting Values."

TABLE 8 - SIGNIFICANT PLACES IN SPECIFIED LIMITING VALUES

Test	Rounded-Off Unit for Observed or Calculated Value
Chemical Composition and Dimensional Tolerances (when expressed in decimals)	Nearest unit in the last right-hand place of figures of the specified limit
Tensile Strength	Nearest 1000 psi
Elongation	Nearest 1%
Stress-Rupture Life	Nearest 0.1 hour

APPENDICES

The following Appendices, included herein for information, present some additional or alternate data and procedures that can be included in tubing specification.

APPENDIX A

TABLE A1
CHEMICAL COMPOSITION

T-111 (Ta-8W-2Hf) ALLOY

Element	Minimum Content ppm	Maximum Content ppm
Carbon*	-	50
Nitrogen*	-	50
Oxygen*	-	100
Hydrogen*	-	10
Zirconium*	-	1000
Molybdenum*	-	1000
Chromium*	-	200
Cobalt*	-	50
Iron*	-	50
Vanadium*	-	20
Silicon*	-	50
Manganese*	-	50
Tungsten	7.0 w/o	9.0 w/o
Hafnium	1.8 w/o	2.4 w/o
Tantalum	Remainder	-

* Total impurities not to exceed 1,500 ppm.

APPENDIX B

TUBING TOLERANCES

CIRCULAR TUBING - These specifications apply to all round tubing.

Average OD. The average of a minimum of four micrometer readings, including the high and low points, equally spaced around the full circumference of the tube.

Ovality. Out-of-roundness or difference between maximum and minimum dimensions of OD, obtained by careful micrometer measurement for high and low points at any one section around the tube. The ovality tolerance is considered to be a total spread inside which both the maximum OD dimension and minimum OD dimension must fall. (For example: On a 1" OD tube with light wall, annealed temper, the total ovality tolerance is a spread of .030". At any one section around the tube, the difference between the minimum OD reading and maximum OD reading shall not exceed .030".)

Eccentricity. Frequently referred to as wall runout, the variation in wall thickness at any one cross section through the tube is the difference between the center of the circle formed by the OD and the center of the circle formed by the ID. It shall be expressed by the term TIR (Total Indicator Reading), which is twice the difference between the center of the OD and the center of the ID. Commercial eccentricity is limited to 10% (20% TIR) of the specified or calculated average wall.

Light Wall. Any wall dimension which is less than 3% of the theoretical average OD.

Normal Wall. Any wall dimension which is 3% or more of the theoretical average OD.

Straightness. All commercial round tubing is subject to a straightness tolerance of 0.010" per foot of length when measured on a straight edge.

Outside Diameter, Inside Diameter, Wall Thickness. All round ferrous, nonferrous, and corrosion resistant alloy tubing shall be subjected to the following commercial tolerances, applicable to only two dimensions.

When specified, the tolerance spread may be applied by the customer as desired. However, when not specified, the tolerances shown below will be applied by the mill.

It should be noted that ID tolerances are based upon the OD range.

TABLE B1 - PERMISSIBLE VARIATIONS IN OUTSIDE AND INSIDE DIAMETER AND WALL THICKNESS

OD Range	OD	ID	Wall
Up to, but not including 3/32" OD	+ 0.002" - 0.000"	+0.000" -0.002"	±10%
3/32" to, but not including 3/16" OD	+ 0.003" - 0.000"	+0.000" -0.003"	±10%
3/16" to, but not including 1/2" OD	+ 0.004" - 0.000"	+0.000" -0.004"	±10%
1/2" to, but not including 1-1/2" OD	+ 0.005" - 0.000"	+0.000" -0.005"	±10%
1-1/2" to, and including 2-1/2" OD	+ 0.010" - 0.000"	+0.000" -0.010"	±10%

The plus and minus 10% commercial wall tolerance shown in the table shall apply down to and including 0.005" wall thickness. For wall thicknesses less than 0.005", commercial tolerance shall be plus and minus 0.005".

<u>Random Lengths</u>. Commercial random lengths in sizes up to, but not including, 1/8" OD, and fragile thin wall tubes over this OD are subject to a length range of 1-15 feet.

Commercial random lengths in sizes 1/8" OD and larger are subject to a length range of 5-24 feet. Long random lengths are subject to a range of 15-22 feet.

Where nominal random lengths on tubing 1/8" OD and larger are specified, a length tolerance of plus and minus 3-1/2 feet applies to the nominal length. This is a total spread of 7 feet.

<u>Cut Lengths</u>. Cut lengths are available up to 39 feet with commercial tolerances as shown in Table B2.

TABLE B2 - CUT LENGTH TOLERANCES

Length	Variations (In.)	
	Over	Under
Up to and including 6"	.010	.010
Over 6" but not including 1'	1/32	0
1' to and including 4'	1/16	0
Over 4' to 10', incl.	3/16	0
Over 10' up to and including 24'	1/8	0
For each additional 10' over 24'	1/8	0

<u>TUBING FOR MATING PARTS</u>

Fitting a tubular part over or into another part or tube causes dimensional problems not ordinarily encountered in nonmating applications. But getting the proper fit is neither difficult nor costly if the tubing is correctly specified.

The American Standards Institute classifies fits into nine categories: loose, free, medium, snug, wringing, tight, medium-force, heavy-force, and shrink. Fits for mating tubing, however, are usually classified in only four categories: loose, free slide, snug, and force. These classifications, which are sufficient for most mating applications, are defined in Table B3 on the following page.

TABLE B3 - CLASSES OF FIT FOR MATING TUBULAR PARTS

Class	Dimensional Range	Character of Fit
Loose	0.003 to 0.005 in. clearance	Allows considerable freedom of movement. Provides clearance under the most adverse environment. There is an upper limit on the clearance, and some fits may be even looser than "loose fit."
Free Slide	0.002 to 0.003 in. clearance	Parts disengage by their own weight if held vertically. This fit is usually considered to be the most liberal fit possible if reasonably accurate positioning is required.
Snug	0.005 to 0.001 in. clearance	Light pressure required to move parts and parts stay in position after being moved. No shake permissible. This is the closest fit that can be assembled by hand without appreciable pressure.
Force or Drive	0.002 in. interference to 0.002 in. clearance	Parts must be assembled with moderate pressure. Provides metal-to-metal contact, with no movement of mating parts after assembly.

Classifications apply to tubing from 0.010 to 1.125 in. OD and to certain light-wall tubing to 2-1/2 in. OD. Light wall refers to wall thicknesses less than 3 percent of nominal OD. Dimensional ranges shown are approximate and are reasonably accurate. The character of the fits described applies generally if the length of overlap is not greater than 6 in., if the mating surfaces are clean and dry, and if the mating parts do not corrode or creep.

APPENDIX C

ULTRASONIC INSPECTION OF REFRACTORY METAL TUBING

There are numerous nondestructive test methods which are applicable to refractory tubing, depending upon what the testing is expected to locate, and upon the degree of porosity of the material. The ultrasonic test can be used, calibrated for a particular material, when the material conducts sound rather well. The ultrasonic test or method of inspection seems to be the preferred approach to tubing certification.

This method is a subject within itself and the issuance of a specification by the purchaser seems to be a more realistic approach to the procedure. In some cases, however, tube producers are not prepared to use procedures that tube users believe are required and this can be a source of controversy. Negotiations thus become necessary and the availability of test facilities, calibration and instrumentation must be mutually established. Of course, one can resort to the use of independent test laboratories that can conduct the testing without difficulty but the problems of communication, distance, etc., arise.

Three preliminary methods are presented in this section on ultrasonic inspection. Procedure C1 is more detailed than Procedure C2 and has been included herein as an illustration of the format. Procedure C3 is a modification of ASTM designation: E213.

PROCEDURE C1

Preliminary specification (03-0001-00-B), dated July 12, 1966, prepared by General Electric, Space Power and Propulsion Section, Cincinnati, Ohio 45215.

C.1.1 General. This process shall be performed on material as early in the manufacturing cycle as practical to avoid possible loss of machining on defective material. Heat treatment of the material shall be completed prior to inspection, except aging or tempering treatments which may be completed after inspection. Whenever possible, material should have flat parallel end surfaces to facilitate inspection.

C.1.2 Surface Finish. Surfaces shall be clean and free of heat treat scale, roughness, and any foreign material which could interfere with the sonic beam penetration and reflection or obscure significant indications. Surface finish shall be no rougher than 125 r.m.s. (ASI 125).

C.1.3 Procedures and Apparatus. Unless otherwise agreed to by the purchaser, the material covered herein will be ultrasonically inspected by the immersion technique at 5 mc (megacycle) frequency or above, and the transducer shall be no larger than 0.75 inch in diameter. For round bar, rod, tubing, and most forgings, inspection shall be accomplished with focussed transducers, preferably cylindrically focused and appropriate to the diameter being inspected. (360-degree beam tranducers with the beam no more than 0.125-inch wide are allowable where internal inspection is appropriate). Cylindrically focused transducers shall be no more than 2 inches in the axial dimension. For bar, rod, tubing, and cylindrical forgings, automatic equipment which traverses a spiral path is satisfactory, but three traverses shall be made: (1) one with the transducer in the circumferential shear position, (2) one with the transducer in the axial shear position, and (3) one with the transducer in the longitudinal wave position. When using a spiral path, the traversing speed shall not exceed one complete revolution per transducer diameter. A reflector may be used for thin sheet if desired, but is not required. Shear wave inspection of plate, sheet, and strip shall be performed in both longitudinal and transverse directions.

C.1.4 Calibration

C.1.4.1 General. Calibration shall be done before and after the ultrasonic inspection or at least at the beginning and end of each work shift. If the magnitude of the indication from the post-test calibration notch differs by 10% or more from the pretest calibration indication, all material inspected since then shall be reinspected. Calibration may be performed on notches cut into the actual material if that portion of the material is to be later trimmed and scrapped, or on material of the same type and similar dimensions (see Table C1). The water path to the calibration part surface shall be recorded, at least by marking the oscilloscope, so that the same distance can be used for the inspection.

C.1.4.2 Shear Wave. Notches shall be cut perpendicular to the surfaces (both inner and outer, where present) in both the circumferential and axial directions, or in two perpendicular directions parallel to the surface, e.g., longitudinal and transverse. Depths of the notch shall be as specified in Table C1, with width no greater than depth, and length greater than beam width but no greater than 0.5 inch. Notches and holes (as discussed below) should be placed so that indications from one will not be confused with indications from another, and at least 0.5 inch from the edge. Where the material thickness is greater than 0.100 inch, an 0.020-inch diameter calibration hole 0.5-inch to 0.75-inch deep shall be made in the calibration piece parallel to the surface at a distance from the surface of 1/2 the thickness (or 1/4, 1/2, and 3/4 the thickness when the thickness is greater than 0.750 inch). Oscilloscope control settings obtained from circumferential shear wave calibration, on internal 0.020-inch diameter holes, shall be used as references for axial shear wave inspection in conjunction with the designated transverse notch. With the search unit directed at the surface of the material, the transducer position shall be adjusted until the internal indication is at a maximum magnitude on either the first or second bounce, whichever is best seen on the oscilloscope. The gain shall be adjusted such that the indication reaches 80% of the oscilloscope scale for the present calibration; this setting shall be recorded for periodic or post-test calibrations. Sound transmissions shall be confirmed either by permanent steady reflection of the first back-surface or other reflecting geometry, or if this is not feasible with the geometry being inspected, then the ability to

detect the calibration notch and set its oscilloscope indication at 80% shall be considered adequate sound transmission.

After the calibration of the internal surface defect and the recording of the gain setting, the gain setting shall be adjusted to achieve 80% on the other calibration notches and holes. The gain setting to achieve 80% on each shall be recorded. Although the evaluation shall be done with the gain setting for the most applicable calibration defect, inspection shall be done at the highest of the above gain settings.

C.1.4.3 Longitudinal Wave. Sound transmission through the material shall be confirmed by observing at least one back reflection before reaching the right-hand side of the sweep.

Where the thickness is greater than 0.100 inch, an 0.020-inch diameter calibration hole 0.5- to 0.75-inch deep shall be made in the calibration piece parallel to the surface at a distance from the surface of 1/2 the thickness (or 1/4, 1/2, and 3/4 the thickness when the thickness is greater than 0.750 inch), unless otherwise specified. Calibration settings to achieve 80% amplitude of the above holes shall be recorded along with the magnitude of other applicable calibration defects. For example, on cylindrical forgings, the hole nearest the near surface should be set at 80% and the amplitudes recorded for the indication from the holes nearer the far surface. The gain settings should be recorded. Similarly gain settings should be recorded to achieve 80% as shown on each of the other applicable calibration defects, recording the amplitudes for all the other calibration holes at each gain setting. For materials less than 0.100-inch thick, no holes are required; the calibration setting shall be that to achieve 80% amplitude on the fourth back reflection.

C.1.4.4 Surface Wave. Whenever the thickness is less than 0.050 inch, or whenever the geometry precludes shear inspection, except where waived by the purchaser, calibration for surface wave inspection shall be performed. Notches perpendicular to the surface and depth 3% of thickness (or 0.001 inch minimum depth to 0.005 inch maximum depth), widths not greater than their depth and lengths greater than the beam width but not to exceed 0.5 inch, shall be placed in a position not closer than 0.5 inch from the edge or other major

surface deviation. Wherever possible, the notches shall be placed in the front and back surface, unless the calibration piece is readily inverted.

The surface wave search unit shall be placed so that the beam is directed toward the broad side of the notch. Sensitivity of the unit shall be adjusted until the indication of the notch is clearly defined and is of 80% amplitude. The sensing unit shall be moved backward until the image disappears from the screen, and then forward until the image is maximized on the screen. Distance shall be measured from some reference on the search unit to the notch so that distances may subsequently be measured properly on the component being inspected.

C.1.5 Test Procedures

C.1.5.1 General. Testing shall be conducted so that all the material in the specimen is scanned during each type of inspection. This can generally be done by moving the search unit or the specimen between each inspection pass either three-fourths of the beam dimension in the direction to be moved, or by moving one-half the transducer dimension in the direction to be moved.

Both shear and longitudinal wave ultrasonic inspection shall be performed on all material except in the case of sheet having thickness less than 0.050 inch where surface wave inspection shall be performed in lieu of the shear wave inspection. To waive any type of ultrasonic inspection, permission must be obtained from the purchaser.

Inspection shall be performed at a rate not to exceed 6 surface inches per second. Focal distance and all other equipment settings during inspection shall be maintained equal to that established in the calibration procedure.

Inspection shall generally be performed at the highest of the calibration gain settings, but the evaluation of indications shall be to the most appropriate calibration defect; that is, surface indications shall be compared to that calibration notch or hole which is at the same distance as the defect or to the calibration notch or hole at the next greater distance. All indications having an amplitude of 60% or greater shall be recorded and included in the report. The approximate depth from the surface of all indications

of 60% or greater shall be recorded and reported. The length of area dimensions of an indication which is relatively continuous at magnitudes varying from 25% to 60% or greater shall be recorded, and reported.

C.1.6 Quality Assurance Provisions

C.1.6.1 Conformance Certification. Unless otherwise specified, the vendor shall furnish with each item inspected three copies of a conformance certificate showing the purchase order number and part number or other identification, and also certifying that the provisions of this procedure wherever applicable, have been met.

C.1.6.2 Reports. Unless otherwise specified, the vendor shall furnish three copies of the inspection results to the purchaser. These reports shall include: (1) a record of all indications having a magnitude of 60% or greater and/or which exceed the magnitude of the appropriate calibration hole or notch, (2) a record of all continuous indications of 25% or greater which are observed over a distance of more than 0.5 inch, (3) a record of all indications from a longitudinal wave inspection which reduce the fourth back reflection to less than 60%, and (4) a record of lesser indications when specifically required by the purchaser. The inspection reports shall also include the above indications accurately delineated with respect to some reference point on the part of specimen, the depth of the defect from the surface and the magnitude of the defect in percent amplitude. The report should also contain the equipment serial numbers, calibration amplitudes and gain setting, a description of the standard used for calibration, and angles related to the method or inspection technique.

C.1.6.3 Surveillance. The inspector or such person or persons designated by the purchaser to determine conformance to this specification, shall be permitted free access to the inspection area to witness or inspect testing operations. The vendor shall afford the inspector all reasonable facilities to assure that the testing process is being performed in accordance with the specified requirements.

TABLE C1. CONSOLIDATED CALIBRATION STANDARDS FOR VARIOUS TUBING AND PIPE SIZES*

Size	Calibration Standard and Notch Description	
	3% Notch Criteria**	5% Notch Criteria**
0.240" -0.400" diameter - wall thickness < 0.050"	0.001" for any diameter within this range.	5% of any actual thickness for any diameter within this range with 0.001" minimum notch.
- wall thickness > 0.050"	3% of wall thickness for any diameter within this range or 0.005" whichever is less.	5% of actual wall thickness for any diameter within this range.
0.360" -0.640" diameter - wall thickness < 0.060"	3% of any wall thickness for any diameter within this range.	5% of any wall thickness for any diameter within this range.
- wall thickness > 0.060"	3% of any wall thickness for any diameter within this range or 0.005" whichever is less.	5% on any wall thickness for any diameter within this range or 0.010" whichever is less.
0.600" -0.900" diameter - wall thickness < 0.080"	3% of any wall thickness for any diameter within this range.	5% of any wall thickness for any diameter within this range.
- wall thickness > 0.080"	3% of any wall thickness for any diameter within this range or 0.005" whichever is less.	5% of any wall thickness for any diameter within this range or 0.010" whichever is less.
0.700" -1.600" diameter - wall thickness < 0.120"	3% of any wall thickness for any diameter within this range.	5% of any wall thickness for any diameter within this range.
- wall thickness > 0.120"	3% of any wall thickness for any diameter within this range or 0.005" whichever is less.	5% of any wall thickness for any diameter within this range but not to exceed 0.010".

TABLE C1 (cont'd)

Size	Calibration Standard and Notch Description	
	3% Notch Criteria**	5% Notch Criteria**
1.200" -3.100" diameter - wall thickness $<$ 0.120"	3% of any wall thickness for any diameter within this range.	5% of any wall thickness for any diameter within this range.
- wall thickness $>$ 0.120"	3% of any wall thickness for any diameter within this range but not to exceed 0.005".	5% of any wall thickness for any diameter within this range but not to exceed 0.010".
2.00" -5.500" diameter - wall thickness $<$ 0.120"	3% of any wall thickness for any diameter within this range.	5% of any wall thickness for any diameter within this range.
- wall thickness $>$ 0.120"	3% of any wall thickness for any diameter within this range but not to exceed 0.005".	5% of any wall thickness for any diameter within this range but not to exceed 0.010".
Above 5.500" diameter	Either "sheet and plate" calibration standards may be used or tubing standards may be prepared based on "sheet and plate" thickness equivalent to the wall thickness as shown previously.	

* See purchase order, design drawings, or materials specification for designated notch criteria.

** Notch Description: The notch shall have a depth dimension as indicated and a width no greater than the depth; the lengths shall be greater than the beam widths but no greater than 0.5 inch.

PROCEDURE C2

NASA-CR-54761, dated October 1, 1965. Potassium Corrosion Test Loop Development, Topical Report No. 3. "Material Specifications for Advanced Refractory Alloys" by D. N. Miketta and R. G. Frank. (Contract NAS3-2547). General Electric, Space Power and Propulsion Section, Missile and Space Division, Cincinnati, Ohio 45215.

C.2.1 Method and Equipment. Ultrasonic inspection shall be by the immersed technique at 5 mc or higher frequency using focused transducers. Inspection shall be by both circumferential and axial shear techniques with longitudinal wave being added when the wall thickness is greater than 0.150 inch. For longitudinal wave technique and for circumferential shear, transducers up to 2 inches long may be used with or without automatic equipment to rotate the tube past the transducer. If spiral pattern inspection transverse is not used, steps must be taken to assure that the ultrasonic beam remains in the same position relative to the tubing so the beam-to-tubing angle remains constant. For axial (longitudinal) shear, transducers must have no greater than 0.5 inch axial length. Transducers must be cylindrically focused for a diameter range which includes the tubing on which it is to be used.

C.2.2 Calibration. Calibration shall be on notches (a total of four, two axial and two circumferential), cut in the tube on both the outside and inside surface unless otherwise specified. The depth of the notches shall be 3% of the wall thickness to a minimum depth of 0.001 inch; the width, no greater than depth; the length, at least that of the ultrasonic beam with a maximum length of 1 inch. Material having a wall thickness greater than 0.150 inch shall also have a 0.020-inch diameter hole machined into the wall in the longitudinal direction at midpoint of the wall thickness. Focusing shall be done to maximize the indication from the inside diameter notch placed properly for the type of inspection contemplated. After focusing is completed, the inside diameter indication shall be set at 80% and gain setting recorded. Gain setting for 80% on the outside diameter notch shall also be recorded. Inspection shall be at the gain setting for the inside diameter indication. A distance corresponding to the wall thickness shall be marked on the oscilloscope. Focal distance to the part to be inspected

shall be set to that used for the calibration piece before beginning inspection. Calibration shall be done both before and after the inspection or at the beginning and end of each work shift. If calibration has changed (gain change greater than 5%), all inspections since the previous calibration shall be repeated.

C.2.3 Rejection. Rejection shall be by any indication which exceeds the amplitude of the respective calibration indication; i.e., inside diameter defects shall be compared to the indication from the notch on the inside diameter and outside diameter defects shall be compared to the indication from the notch on the outside diameter. Defects less than half the thickness from the surface or less than 0.150 inch from the surface, whichever is smaller, shall be compared to the outside diameter calibration indication. Defects more than half the thickness from the incident surface or more than 0.150 inch from the surface shall be compared to the indication from the inside diameter calibration notch.

C.2.4 Reports. The ultrasonic inspection report shall contain the equipment serial numbers, calibration amplitudes and gain settings and the amplitude and location of each defect whose amplitude is 60% greater.

PROCEDURE C3

Simplified specification recommended by the Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831.

Ultrasonic inspection shall be performed on all tubes in strict accordance with ASTM E213 and as specifically listed below represent modifications incorporated in similar sections of ASTM E213.

Section 1 - This inspection shall be by immersion inspection only and shall be for the detection of transverse as well as longitudinal discontinuities. It shall be applied to tubular products of any diameter and wall thickness, unless otherwise specified in the purchase order. The inspection shall be conducted at the completion of the manufacturing operation. No cold working shall be performed after the ultrasonic inspection, except for minor hand straightening.

Section 5 - Both longitudinal and transverse notches shall be electric-arc discharge machined in the inner and outer surface.

(c) The notch dimensions shall be:

Depth - The depth shall be 3% of the wall thickness or 0.0020 inch, whichever is greater. The transverse notch shall be cut with a tool preshaped to the curvature of the surface being notched so that the notch bottom shall be approximately concentric to the surface.

Width - The width shall be no greater than the depth, except that the minimum required width shall be 0.003 inch.

Length - (1) The length of the longitudinal notches shall be approximately equal to the wall thickness or 1/4 inch, whichever is greater. (2) The transverse notches shall be 1/4 inch chordal length, or the chord of a 30° arc on the surface being notched, whichever is the lesser. (Note: Other notch lengths or depths may be specified by the purchaser to conform with the material requirements. Care must be exercised when specifying smaller notches to ascertain that the test is possible.)

The tolerance on the notch depth shall be $\pm$ 10% of the calculated depth for notches less than 0.005-inch deep.

Section 6 - Calibration of Apparatus

A. Longitudinal

Using the calibration standard, the equipment shall be adjusted to produce signals as nearly as possible the same height from both the inside and outside longitudinal notches. The standard shall then be scanned with a feed helix no greater than the lesser of one-half the notch length or one-half the beam width at the outside surface of the standard.

B. Transverse

The equipment shall be adjusted so that the relative response from the inner and outer surface transverse notches is as nearly equal as possible. At a chosen sensitivity level the standard shall be rotated to obtain a signal from one of the notches. Without further tube rotation the transducer shall be moved longitudinally with the tube axis to the point where a maximum signal is received. This point shall be noted and the transducer again moved a distance which will reduce the signal amplitude to the minimum flaw alarm (reject) level. The distance moved between the maximum amplitude position and the reject level position shall be termed the travel distance. This travel distance shall be determined for the other notch in a like manner. The pitch of the scan helix shall be no greater than 90% of the lesser of the two distances found.

Section 7 - Inspection Procedure

The material shall be tested with the sound propagated longitudinally and in both circumferential directions under conditions that are used for calibration of the equipment.

Section 8 (a) - Interpretation of Results

All indications of discontinuities detected with the test system calibrated on the longitudinal notches shall be compared to the longitudinal notches only. All indications of discontinuities detected with the test system calibrated on the transverse notches shall be compared to the transverse notches only. All indications which are equal to or greater than the lesser indication of the appropriate notches shall be cause for rejection of the pipe or tube.

APPENDIX D

MECHANICAL OR DESTRUCTIVE TESTING

Whether or not finished tubing meets mechanical requirements of end-use service is determined by a number of different types of tests. Included in these are:

Tension Test: Checks the yield point, tensile strength and ductility of the material.

Hardness Test: Generally performed on the tube ID using a Rockwell or other hardness testing machine. Checks hardness of the material. Hardness is related roughly to heat treatment and strength of material.

Deformation Tests: In order to determine the quality of a weld (if any) and the ductility of the metal flange, flare, flattening and reverse-flattening tests are performed as deemed necessary to assure meeting the end-use requirements.

The above types of tests are most often specified in tubing material specifications and have achieved some form of standardization.

However, there is another type of tension test that has received some attention in the field of plastic materials and which may be employed for metallic tubes. This is the Naval Ordnance Laboratory (NOL) ring-type tensile test.

NOL Ring-Type Tensile Tests

The NOL ring test is another method for tensile testing of tube specimens. In the tube or pipe specimen the ring is a narrow length of tubing, say 1/4 inch, of a specific inside diameter. This narrow ring specimen is inserted into a split-disk type grip where the split disk is cut from an original one-piece disk whose outside diameter is equal to the inside diameter of the ring specimen. When the ring specimen is inserted into the split-disk fixture, the gap between the two disk halves is about 1/16-inch before a load is applied to the assembly. With this arrangement, the rings are subjected to an essentially uniaxial tensile loading across the small gap between the two disk halves. In order to promote uniform slippage of

the ring inner surface with respect to the ring-loading surface (due to strain within the specimen), the ring-loading surface of the split-disk fixture is lubricated. The selection of the lubricant is dependent upon the environmental test environment. Teflon TFE powder is one such typical lubricant.

A conventional tensile loading system incorporating universal joints (for alignment purposes) can be utilized.

Strain in the NOL rings is determined by the gap growth between the two disk halves. A linear variable differential transformer can be employed to measure gap growth. The total strain is taken as two times the gap growth, and the total strain is assumed to be distributed uniformly throughout the mean circumference of the ring.

It should be noted that for tubing specimens the diameter of the tube can impose restrictive test conditions.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Materials Advisory Board Committee on Tubing	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

GUIDELINES FOR REFRACTORY ALLOY TUBING SPECIFICATIONS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Materials Advisory Board Committee on Tubing

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1967	46	--

8a. CONTRACT OR GRANT NO. DA-49-083 OSA 3131	9a. ORIGINATOR'S REPORT NUMBER(S) MAB-232-M
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Department of Defense

13. ABSTRACT

The report constitutes precautions, limitations, and guidelines which are intended to facilitate the preparation by a user of a specification for procuring tubing made from reactive or refractory metals.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Tubing						
Columbium						
Molybdenum						
Tantalum						
Tungsten						
Vanadium						
Specifications						
Composition						
Properties						
Dimensional Tolerances						
Discontinuities						
Contamination						
Test Methods						
Inspection						

Unclassified

Security Classification

THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as official—yet independent—advisor to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE MATERIALS ADVISORY BOARD is a unit of the Division of Engineering of the National Research Council. It was organized in 1951 under the name of the Metallurgical Advisory Board to provide to the National Academy of Sciences advisory services and studies in the broad field of metallurgical science and technology. Since the organization date, the scope has been expanded to include organic and inorganic nonmetallic materials, and the name has been changed to the Materials Advisory Board.

Under contracts between the sponsors and the National Academy of Sciences, the Board's present assignment is to conduct studies, surveys, make critical analyses, and prepare and furnish to the sponsors advisory and technical reports, with respect to the entire field of materials research, including the planning phases thereof.

3-67